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Report to Congress

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16. ABSTRACT Research on ozone protection has been coordinated under the Biological and Climatic Effects Research (BACER) Program. This is a multiagency, multidisciplinary effort initially funded by The Environmental Protection Agency. Its purpose is to reduce uncertainties regarding ozone depletion to improve regulatory decision-making. Health, biological, ecological, climatic and social/economic effects are studied. Activities include surveys of skin cancer among populations at different latitudes, measurements of solar UV-B (290-320 nm) at the sites, tests of over 100 plant species under simulated and natural UV-B levels, experiments with aquatic ecosystems, and social/economic workshops. Results to date are as follows: surveys generally support belief that skin cancer incidence is related to UV-B exposure; mortality from skin cancer is increasing among the young, probably due to changes in life style--more time outdoors; all plants tested are sensitive to UV-B at some exposure level; some plants are stunted, others suffer bleached or discolored leaves; UV-B damages larvae of shrimp, crab, mackerel and anchovy; photorepair mechanism is suggested as a potential mitigator of UV-B effects in plants; field type, medium resolution spectroradiometer and calibration standards were developed; and a conceptual model, including parameter uncertainties, is developed for integrated assessment of costs/benefits of control vs. non-control. Reliability of assessments increase as parameter uncertainties decrease--do not have to revise model for new data.

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RESULTS OF RESEARCH RELATED TO STRATOSPHERIC OZONE PROTECTION

REPORT TO CONGRESS

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PREFACE

This report is submitted to Congress in compliance with Section 153(g) of the Clean Air Act Amendments of 1977, Public Law 95-95 [PL 95-95]. The law requires that the Administrator of the Environmental Protection Agency, as part of the program for ozone protection, shall "not later than January 1, 1978, and biennially thereafter,. . .report to the appropriate committees of the House of Representatives and the Senate, the results of the studies and research conducted under Section 153 and the results of related research and studies conducted by other Federal agencies." As is indicated in the Executive Summary, some research was underway prior to passage of PL 95-95. In September 1977, as part of the response to Section 153 of PL 95-95, the Agency conducted a multidisciplinary and multiagency workshop to review research and to provide a basis for further planning of research. The purpose of the symposium was to provide outputs to support regulatory decision-making and provide a better basis for optimum protection of public health and welfare from ozone depletion caused by human activities.

In order to accelerate and improve the quality and focus of research, the Agency program on Biological and Climatic Effects Research (BACER) contracted with SRI International (SRII) for scientific and technical support. SRI International, as part of the work under that contract, prepared this initial overview, under the direction of Dr. Alphonse F. Forziati, Director, and members of the Stratospheric Modification Research Staff.

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I EXECUTIVE SUMMARY

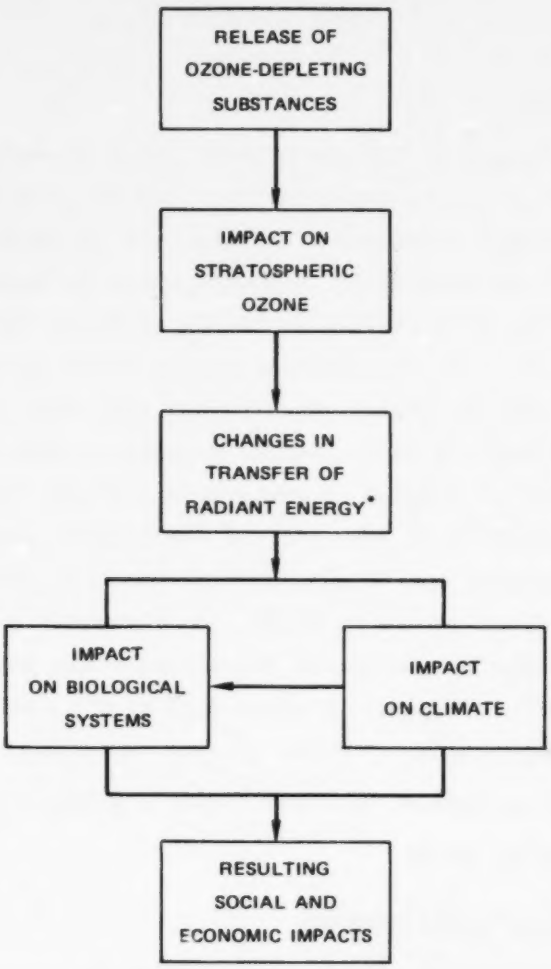
A. Introduction

The possibility of a need to protect the stratospheric ozone layer against man-made causes of depletion first arose in connection with emissions from supersonic aircraft. To study such concerns the Climatic Impact Assessment Program (CIAP) was undertaken by the Department of Transportation from 1970 to 1974 at the direction of Congress. This was followed by concern over the possible depletion of ozone due to the release of chlorofluorocarbons (CFCs). The Federal Committee on Science and Technology requested the Environmental Protection Agency (EPA) to take the lead in a Federal program to study this problem, and in 1976 EPA reprogrammed $4 million of Research and Development funds to support a multiagency Biological and Climate Effects Research (BACER) program. In August 1977, Congress passed PL 95-95, the Clean Air Act Amendments of 1977, which includes a mandate for EPA to undertake and coordinate Federal Research to ascertain impacts of ozone depletion on public health and welfare, and human-generated causes of such depletion. This document is the first report on Federal Research required biennially under Section 153(g) of PL 95-95.

B. Findings to Date--An Overview

This section summarizes the results of BACER-supported research and related studies. It does not describe all the relevant research results obtained by other federal agencies, since Section 154 of the Clean Air Act requires them to submit separate reports. Reports from these other federal agencies complement the present document. To the extent possible, their results are integrated into this summary.

As illustrated in Figure 1, the uncontrolled release of ozone-depleting substances to the atmosphere has far-reaching implications. The resulting effects are not limited to the United States, but are


RELEASE OF OZONE-DEPLETING SUBSTANCES
IMPACT ON STRATOSPHERIC OZONE
CHANGES IN TRANSFER OF RADIANT ENERGY*
IMPACT ON BIOLOGICAL SYSTEMS
IMPACT ON CLIMATE
RESULTING SOCIAL AND ECONOMIC IMPACTS

* Includes both ultraviolet radiation (notably UV-B, 290 to 320 nanometers wavelength), visible, and infrared (IR) radiation.

FIGURE 1 EFFECTS RESULTING FROM RELEASE OF OZONE-DEPLETING SUBSTANCES

distributed globally. There are many uncertainties and unknowns in each research area, and concerning the relationships among research areas. The general objective of the research to date has been to reduce these uncertainties, probe into certain areas where knowledge is meager, and quantify ozone-depletion impacts wherever possible.

Recent research suggests that if chorofluorocarbon (CFC) releases were to continue at the 1975 rate, a stratospheric ozone depletion of over 10% could occur in three to five decades. This would affect the transfer of solar energy in the atmosphere. Current capabilities to assess the impact of such depletion on weather and climate are limited to approximate predictions of globally averaged temperature decreases. (The current predicted decrease is less than 0.2°C.) However, ozone depletion could also have large effects on local and regional weather, including precipitation. Unfortunately, current lack of information on this issue limits the ability to make useful predictions.

Since the stratospheric ozone layer shields the earth's atmosphere, surface, and waters from damaging ultraviolet wavelengths between 290 and 320 nm (UV-B), the estimated ozone depletion will also result in increases of UV-B dosages to all exposed biological systems. Therefore, much of the current research has focused on analyzing the effects of increased UV-B exposures on humans and nonhuman biological systems.

Since humans are not exposed experimentally to controlled dosages of UV-B, assessments of the effects of UV-B exposure on human health are largely based on demographic studies using epidemiological data. The emphasis has been on analyzing skin cancer incidence rates. Relevant BACER projects are described in detail in Section II of this report. The most significant health findings to date are:

- For the population as a whole, the incident of melanoma of the skin has substantially increased in recent years; for adults under age 65 an increase in non-melanoma skin cancer has also occurred.
- Skin cancer incidence of all types is believed to be directly related to UV-B exposure.
- Some sub-populations (i.e., skin types, ethnic groups, and so forth) are more susceptible to increases in skin cancer incidence than are others.

There is thus a basis for inferring that an increase in UV-B radiation at the earth's surface resulting from stratospheric ozone depletion could lead to an increase in the incidence of both melanoma and non-melanoma skin cancer in certain sections of the population. Current studies are attempting to quantify or refine the above findings.

Other biological (ecological) systems have been experimentally exposed to controlled dosages of UV-B. Nevertheless, the problem of quantifiying these biological effects is enormous. Only a relatively few major plant and animal groups, primarily higher plants, have been tested. In spite of this limitation, BACER and previous research leads to the following conclusions:

- Small increases of UV-B appear to inhibit photosynthesis in some terrestrial and aquatic plants and at least some nitrogen fixing mechanisms.
- Plant species possess the capability for some repair of UV-B damage when exposed to full sunlight in the visible portion of the spectrum but this repair does not prevent significant reductions in the yields of sensitive species.
- Shifts in the composition of both aquatic and terrestial plant and animal communities are probable, and some of these shifts appear likely to significantly damage commercial fisheries.

It can thus be stated that an increase of UV-B radiation at the earth's surface resulting from stratospheric ozone depletion would probably have significant ecological impacts. However, there is a lack of means to assess and predict sensitivity of various ecological systems to increased UV-B radiation. Further effort is necessary to quantify such sensitivity before social and economic impacts can be evaluated.

The effects of ozone depletion summarized above have many indirect social and economic consequences. The specification of these consequences has been limited by the availability of data on the nature and magnitude of the primary effects (on humans, other biological systems, and climate). While monetary costs can only be approximated due to the uncertainties, it is generally acknowledged that over a few decades these costs (e.g., health care, and agricultural losses) could amount to hundreds of billions of dollars. Hence, from the monetary point of view alone, there is a

strong motivation to investigate regulatory alternatives. Section II contains a more detailed discussion of these social and economic impacts.

Improved instrumentation and monitoring are vital to research on ozone-depletion impacts. A significant portion of the funds available for this research has been spent on development of (1) improved UV-B sources and instrumentation, (2) additional UV-B monitoring, and (3) analysis of the resulting data base. Under Item 1 above, the Norris spectroradiometer was developed for biological effects research. Also, a submersible spectroradiometer is being evaluated to study the potential effects of UV-B radiation on the aquatic environment. In an effort to improve the accuracy of a variety of UV-B sources and detectors, the National Bureau of Standards (NBS) has established a quality-assurance procedure that will ultimately reduce field measurement errors to less than 10%. (Currently these range as high as 45%.)

Additional UV-B monitoring (Item 2) was undertaken by the National Oceanic and Atmospheric Administration (NOAA) at the key epidemiological locations, as identified in the National Cancer Institute (NCI) skin cancer studies. Under Item 3, analysis of existing NOAA data has resulted in a verification that the ratio between UV-B enhancement and ozone depletion is very close to the theoretically predicted value of 2 (i.e., a 2% increase in UV-B for every 1% decrease in ozone).

Again, it is emphasized that more data and research are needed to reduce the uncertainties associated with estimation of impacts caused by ozone depletion. Section I-C addresses needs for future developments that will lead to an improved data base and more accurate appraisal of the impacts involved.

C. Future Research Needs

A potential for significant adverse environmental effects has been suggested by research accomplished to date. Examples are skin cancer incidence, effects on larvae of commercially important fishes, marine organisms such as phytoplankton and zooplankton, and certain plants used as food. More data are needed in all areas (i.e., human health, other biological/ecological systems, climate monitoring, economics, and social

issues). The general research requirements are outlined here. Section II contains a more detailed description of these requirements.

Research needs are separated into short-term and long-term programs. Short-term programs are those that will return substantial quantitative knowledge within a one- to two-year period. The longer-term research program objectives are to broaden the base of knowledge and further reduce uncertainties and to identify and quantify the direct and indirect effects of ozone depletion on human health, and ecological, geophysical and socio-economic systems.

1. Human Health

Short-term benefits can be derived from continuing (1) the analysis of existing morbidity and mortality data to quantify the relationship between the ozone depletion and skin cancer, and (2) the operation of the NOAA Robertson-Berger Network at the 10 key locations for which there are epidemiological data. Other projects with longer-term payoffs include expanding the data base for non-melanoma skin cancers, characterizing high-risk individuals, and acquiring basic information on skin cancer induction through studies on animals.

2. Nonhuman Biological Systems

The most pressing research needs in nonhuman biology are the development of validated predictors of UV-B sensitivity; the replication of eye-cancer studies using smaller, less expensive laboratory animals; and extension of the analysis of ways in which organisms are affected by UV-B and photosynthetically active radiation. Equally important but more time-consuming needs are the expansion of experimental studies of the effects of UV-B on interactions among plants, animals, and microbes; and studies to verify preliminary data on pollinators.

3. Climate Effects

Because of the wide range of activities and the large number of scientists conducting climate-related research, a yearly workshop

concerned with the role of stratospheric ozone in weather and climate would be highly beneficial. The workshop would help promote a high level of information exchange and thus establish the framework for future research. Other programs that would produce results in the near term include (1) continuation of the statistical analysis of existing climatological data, and (2) the evaluation of the effect of increased UV-B on photochemi al smog. Longer-term needs call for the improvement in climate and general circulation models, and the measurement of atmospheric trace substances (including aerosols) that influence the climate.

4. Monitoring and Instrumentation

Monitoring of UV-B radiation (or related parameters) is essential for establishing a data base to support studies on the effects of ozone depletion. The Robertson-Berger network should be continued, and should result in short-term benefits in skin cancer studies (as mentioned in Section I-C-1, above), and other biological/ecological studies as well. The NBS quality-assurance program should be continued, to ensure that measurements are supported by frequent calibrations against known standards. Other measures with long-term benefits include development of a spectroradiometer network, continued tests on the immersible spectroradiometer, and development of personal dosimeters.

5. Integrated Assessment

An integrated assessment of ozone-depletion effects, resulting costs, and social consequences must be undertaken to provide suitable information on which to base regulations. Basically, three programs are needed for this purpose. The first, an interdisciplinary workshop, would provide a forum in which economists and other scientists could exchange information on the costs and risks of control versus non-control. The second need is an optimum control model, which provides the framework for quantitative assessments that are essential in the regulatory process. The third need is for an objective method by which future research can be given priorities. Ideally, the method will help identify what new information will contribute most to the regulatory decision process.

II TECHNICAL DISCUSSION

A. Introduction

This section treats the background, current research areas, and future needs in more detail than the Executive Summary. The findings are based on research to date for several projects that are still in progress. Therefore, much of this discussion relies on interim results.

B. Human Health

1. Background

Even before the institution of the BACER program, a clear relationship between sunlight exposure and skin cancer other than melanomas was commonly accepted. It was known that there was an inverse relationship between these cancers and latitude, that the high-risk individuals were those who spent a great deal of time out of doors, such as sailors and farmers, and that blacks were a low-risk group. Because albino blacks were known to be at high risk, a genetic explanation other than pigmentation was ruled out.

There was also highly suggestive evidence that sunlight was a cause of malignant melanoma. Mortality and incidence rates of malignant melanoma had been found to be higher with decreasing latitude (Lancaster, 1956; Lee and Merrill, 1970; Cutler and Young, 1975), and blacks had been found to be at low risk for melanoma (Lancet Editorial, 1971).

Several mathematical models had been proposed to predict the potential effect of ozone reduction on skin cancer incidence other than melanoma (Urbach et al., 1974). These models were based on data from the National Cancer Surveys. Early models predicted that a 1% decrease in ozone would result in a 2% increase in incidence rates for these cancers. However, later studies suggest a 4% increase in cancer incidence rates for a 1% decrease in ozone.

2. Current Research

a. Acquisition and Analysis of Epidemiological Data on Skin Cancer

BACER funds support three projects currently under way in this area. The largest project is being conducted by the National Cancer Institute. It consists of reviewing all newly diagnosed skin cancers other than malignant melanomas within several geographically defined populations. These populations are participating in the SEER (Surveillance, Epidemiology, and End Results) program. These populations allow direct comparisons between geographic latitude and age-adjusted incidence rate for skin cancer other than melanoma. To the extent possible, NCI will also try to correlate cancer incidence rates with more direct measurements of UV-B flux. These data are not routinely available from existing sources such as cancer registries as are corresponding data for malignant melanomas; this is probably because skin cancers other than malignant melanomas are usually treated in physicians' offices or outpatient clinics rather than hospitals.

A second project is being conducted at the Department of Statistics of the University of California at Berkeley. In this approach, UV-B exposure data are correlated with existing data on skin cancers, including data obtained at locations selected for the Health and Nutrition Examination Survey (HANES), the National Ambulatory Medical Care Survey, and the Survey of Discharges from Short Stay Hospitals--all surveys run by the National Center for Health Statistics. Considerable meteorological data including cloud cover information are being collected for each of the 65 HANES locations and for other survey locations as well. The investigators plan to correlate the meteorologic indicators of UV-B exposure with the skin cancer rates to try to estimate more exactly the increases in skin cancers resulting from increases in UV-B exposure.

The third project, being conducted at the Department of Epidemiology at the University of Washington, consists of a detailed analysis of existing data sources for skin cancer. One set is U.S.

mortality data on all skin cancer, both melanoma and non-melanoma, that are available from 1931 to 1974. Beginning with the eighth revision of the International Classification of Diseases in 1968, the melanomas can be analyzed separately from the non-melanomas. Before 1968, the assumption has been made that 95% of the deaths from skin cancer between the ages of 20 and 64 were caused by melanomas. Most of the work has involved dealing with trends only for individuals between the ages of 20 and 64.

The purpose of this study at the University of Washington is to take the long-standing existing mortality data that are routinely reported, and break these mortality rate trends over time into various components, with the hope that models can then be constructed from which future predictions can be made and compared with actual trends. This would allow more precise correlation of ultraviolet flux with the incidence rate for malignant melanoma and for other skin cancers. Thus far this analysis of U.S. mortality data has identified different components of the overall trend. The overall skin cancer mortality rates have shown a decrease since 1931. However, this decrease is confined to ages 65 and over; younger ages have shown an increase over time. The increasing mortality rate in the younger age groups is due to an increasing incidence rate for malignant melanoma. This increasing rate has been documented elsewhere and has been shown to be primarily occurring as a result of a change in risks over generations, with people born later having higher rates at the same ages than people born earlier. This is known technically as a birth cohort effect. However, the rate of increase of mortality with age is considerably lower at older ages for the later-born cohort than it was for the same ages in those born earlier. If the slope of these curves for each age is plotted, it is clear that this decline in slope is not a function of age. However, when the slope data are rearranged versus time, it is clear that there has been a general decline in the rate of increases of mortality with age. Mortality rates for the rest of the century have been projected based on a continuation of these trends in birth cohort effects and the change of slope in mortality with age.

To check on the possibility that the decline in the rate of increase of mortality rates with age could be the result of increased early recognition and treatment of these cancers, the Connecticut Cancer Registry incidence data were studied and no evidence was found of a decline in the rate of increase in incidence with age. Apparently, there was a steady improvement in early recognition and treatment of melanomas, and in fact, the case fatality rate for malignant melanoma has been decreasing. It therefore appears that the overall decreasing trend in skin cancer mortality rates is a result of decreased case fatality rate for malignant melanoma in spite of an increased incidence rate for skin cancer in general, which is a result of a birth cohort effect reaching a peak in individuals born about 1931.

b. Identification of the Groups Susceptible to Skin Cancer

Two projects that were funded in FY 1977 were designed to identify the sub-population most susceptible to skin cancer. One project was led by the National Cancer Institute. At present, NCI is determining whether a case control study of skin cancers other than melanoma can be carried out by telephone survey alone or by a mail questionnaire in addition to a telephone survey. The study is being pilot-tested in the Minneapolis-St. Paul SMSA* using skin cancer cases documented in the Third National Cancer Survey. Among the factors being investigated are skin complexion, number of hours spent outdoors, clothing habits, frequency of sunbathing, use of suntan oil and other sun screens, ease of tanning, ease of burning, use of sun lamps, chemical exposure history, skin conditions (such as acne, oily skin, dry skin, moles, freckles, psoriasis, warts, hair loss, and hives), and the eye and hair color. The investigators intend to match cases and controls for age, sex, and race.

The second project is being carried out by The Department of Dermatology at Massachusetts General Hospital. This study is intended to be a case control study of malignant melanoma. The controls will be

*Standard metropolitan statistical area.

matched to cases according to age and sex within the same neighborhood so that their socioeconomic status will presumably be similar. The investigative team plans to obtain histories of exposure to sunlight according to the time in the individual's life, such as childhood, first job or college, marriage, and other life periods, and not according to specific ages. The individuals will also be asked about their recreation patterns and exposure to chemicals. The investigators are interested in contrasting the risk of disease for relatively brief but intense exposures to sunlight with the risk for low-level exposures continued over a long period of time, which might result in the same total dose. These risks will then be compared with those for relatively non-exposed individuals. The pilot study will explore behavioral attitudes of cases and controls toward sunlight exposure. Further, it will obtain information on physical characteristics such as skin, eye, and hair color, that might be important variables.

3. Future Needs

Future needs are summarized in Table 1. Studies on melanoma skin cancer incidence can provide meaningful results in the near term because the data base is adequate (though in need of improvement). The same is not true for the non-melanoma skin cancer data base. Therefore, this data base must be expanded--a time-consuming process with long-term payoffs. Hopefully, studies on animals can lead to a more basic understanding of the mechanisms involved, both for melanoma and non-melanoma skin cancers.

C. Nonhuman Biological Systems

1. Background

The biological effects of UV-B (290 to 320 nm radiation) received little attention prior to the BACER and CIAP programs. The major achievements before these programs started were a preliminary, qualitative assessment of the effects of UV-B and the evolution of generally accepted methods of experimentation using commercially available lamps and filters.

Table 1

HUMAN HEALTH RESEARCH NEEDS

Research Needed	Benefits
• Epidemiological Data Analysis. Continue the analysis of existing morbidity and mortality data to quantify the relationship between ozone depletion and skin cancer.	Short term
• UV Radiation Monitoring. Ensure that UV flux measurements are being made in locations where epidemiologic data are being collected.	Short term
• Nonmelanoma Data. Collect data in order to calculate incidence rates for non-melanoma skin cancer in defined geographic areas.	Long term
• High-Risk Groups. Characterize high-risk individuals by conducting case-control studies of both melanoma and skin cancers other than melanoma.	Long term
• Animal Research. Conduct studies on animals to acquire basic information on the mechanism of skin cancer induction.	Long term

Short-term BACER and associated research by other agencies and institutions has developed better experimental hardware, extended the qualitative assessments of UV-B data, and begun reliable quantification of effects.

2. Current Research

Short-term BACER research in nonhuman biology has focused to date on effects of UV-B radiation on crop plants, primarily as measured in controlled environments. Explorations have been started on the effects of such radiation on agriculturally important crops, insect pests, nitrogen fixation, gas exchange rates in field and horticultural crops

under field conditions, eye cancer in cattle, growth impairment in forest tree seedlings, plant-pathogen interactions, and effects on commercial fisheries. Research sponsored by other agencies has focused upon effects on plant and animal communities.

As a result of the research funded by short-term BACER, and related NASA programs, it can confidently be said that increased UV-B irradiation will cause adverse impacts, but the magnitude of these impacts cannot reliably be estimated. Results to date have demonstrated considerable variation among species, and among cultivars within species; however, no recognizable pattern of interspecific variation has been noted. The most common responses in crop plants are symptoms of reduced growth or delayed maturation, such as reductions in leaf area, height, or weight, and delays in germination. These effects imply reduced crop yields, increased disease susceptibility, and possibly both increases and decreases in the need for pesticide usage, depending on the crop. Implications for fertilizer usage are unclear, since the data base is meager. However, the preliminary findings suggest that some nitrogen fixing mechanisms in algae will be impaired at the increased levels of UV-B irradiation that may occur. Impacts on animals are less amenable to generalization, but preliminary results indicate that increases in UB-V radiation cause reductions in insect lifespan and numbers of offspring per surviving adult, and in delay of development; eye damage in cattle; and the formation of brain and retinal lesions in fishes and aquatic invertebrates. At least some of the aquatic species and perhaps some of the higher plant species studied appear to be at or very near their limits of tolerance of UV-B at the present levels of UV-B irradiation, and thus would be adversely affected by further increases. However, much more precise measurements of natural variations of UV-B incidence are needed to verify this preliminary observation.

In sum, the variation among species in sensitivity to UV-B, and the extreme sensitivity of some species studied, imply that shifts in composition of natural plant and animal communities will occur if UV-B irradiation increases, and perhaps changes in agricultural practices

may be expected. However, quantitative predictions of the size and significance of these changes are not feasible with the current knowledge.

3. Future Needs

To quantify biological, social, and economic impacts, a better connection must be developed between laboratory and field experiments to permit wider extrapolation. For some organisms, such as mammals other than beef cattle, the data base must be extended (see Table 2). Moreover, there remains a pressing need for insight into the damage resulting from UV-B, and possible subsequent repair in the presence of photosynthetically active wavelengths of light.

Acquisition of at least a statistically reliable empirical analysis of the interaction between UV-B, photosynthetically active radiation, and photorepair is needed to permit use of the existing data base in economic and ecological analysis, and should be given the highest priority. While crop losses can be directly measured in field experiments, the preliminary results of the BACER studies suggest that effects will be at the limit of experimental detection in field experiments even under favorable circumstances. Hence, given the variability of weather from year to year, several years of field experimentation would be required to obtain a statistically defensible estimate of the damage to be expected from increased UV-B irradiation.

Roughly the same amount of time is needed to expand the data concerning effects on aquatic organisms. The existing data base is small, but indicative of severe impacts on those species whose larval or other stages remain near the water surface during daylight hours. While the preliminary aquatic experiments, like their terrestrial counterparts, are biased toward overestimation of the hazards, these biases probably are small.

Second but high priority should be given to extension of the data base on effects on animals, particularly on mammals, birds, and aquatic organisms, since the economic and ecological implications of adverse effects on these groups are very great.

Table 2

NONHUMAN BIOLOGICAL RESEARCH NEEDS

Research Need	Benefit
• Photorepair. Extend analyses of the interaction between UV-B and photorepair, validating the results with field experiments to facilitate the extrapolation of existing growth chamber and greenhouse data to field conditions (which is needed for economic assessments).	Short term
• Eye-Cancer Studies. Replicate the eye-cancer studies on Herefords using smaller, less expensive laboratory animals (mammalian and avian species), and simultaneously look for adverse effects other than cancer.	Short term
• UV-B Predictors. Explore potential of predictors of sensitivity to ionizing radiation for use as predictors of UV-B effects, and pursue less circuitous indicators as concepts develop.	Short term
• Interactions among Species. Replicate and expand experimental studies of the effects of UV-B on interactions between plants, animals, and microbial pathogens or symbionts in both terrestrial and aquatic experiments. Particular emphasis should be given to expansion of the data base on zooplankton and fish larvae and N_2-fixing organisms to confirm and extend the available estimates of the magnitudes of the effects of UV-B.	Long term
• Physiological Responses. Extend the studies of the physiological responses of insects to investigations of impacts on behavioral parameters, particularly the ability of bees to pollinate crops.	Long term

Since the connection between ionizing radiation and health effects is fairly well known, exploration of the possibility of a correlation between sensitivity to UV-B and sensitivity to ionizing radiation warrants a small but immediate effort. The potential payoff could be very high if it led to extrapolation of the data base to unstudied species.

The last two items in Table 2 are comparable to the first three in importance, but are unlikely to quickly yield results useful in the regulatory process.

D. Climate Effects

1. Background

Stratospheric ozone depletion would affect the heat balance of the atmosphere by modifying the transfer of radiant energy. The effect, which varies strongly with wavelength, extends across the spectrum including all the UV, through the visible, and into the infrared. As a result, changes would occur in the vertical distribution of temperature and in the surface temperature. In turn this could lead to perturbation of current weather patterns and to local changes in precipitation and temperature.

It is important to recognize that the weather changes due to ozone depletion that are of greatest concern are regional and seasonal changes rather than changes in the global, annual averages, and this is particularly so in the case of precipitation incidence (Geisler 1977; Strommen, 1977). Thus, very serious impacts could occur without being reflected by large changes in such indicators as globally averaged annual temperature.

These points are illustrated by several examples in Section II-F. One of the examples is the anomalous winter of 1976-77, during which the eastern United States suffered record cold and heavy snowfall (Wagner, 1977a, b; Dickson, 1977a) while California experienced a record drought (Dickson, 1977b). It is now generally recognized that the severe weather of the 1976-77 winter was associated with a change in the wave-like flow of weather systems from their normal pattern to the one shown in Figure 2. The 1976-77 pattern diverted normal rainbearing storms away from the western United States (causing the severe drought there) and brought Canadian and Arctic weather systems southward into the eastern United States. Yet in spite of the resulting dramatic impacts on

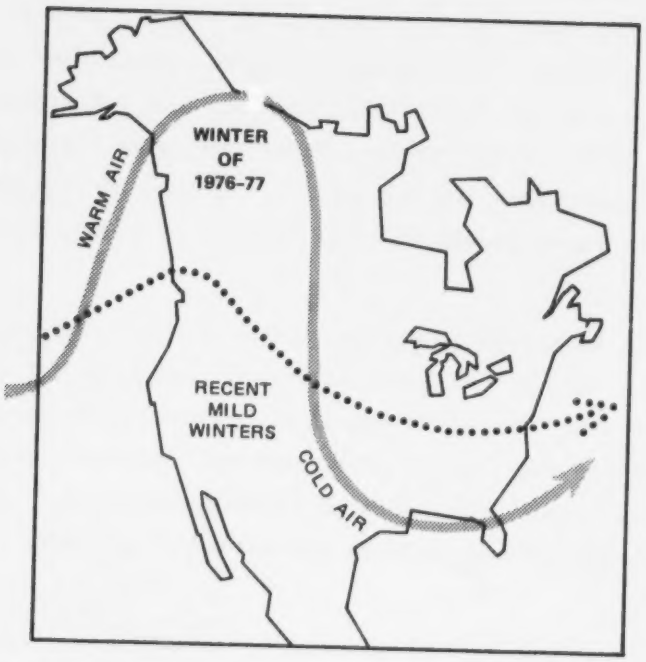


FIGURE 2 CHANGE IN FLOW OF WEATHER SYSTEMS THAT CAUSED ANOMALOUS WINTER OF 1976-1977

U.S. weather, the weather anomalies of winter 1976-77 had little, if any, impact on global average surface temperature (Geisler, 1977).

The wavelike flow of weather systems shown in Figure 2 results from many factors but is affected by latitudinal temperature differences and the stratospheric temperature profile, which are in turn affected by changes in the height, amount, and latitudinal distribution of stratospheric ozone. Hence, the most important climatic effect of stratospheric ozone depletion could very well be to contribute to changes in the current "normal" pattern of these wavelike weather flows. A complete understanding of the climatic effects of ozone depletion thus requires an ability to predict ozone effects on these atmospheric planetary waves.

In order to be able to assess the impact of perturbations of this type it is necessary to have a methodology capable of linking changes in the ozone layer to such changes in atmospheric dynamics, and their resulting changes in temperature and precipitation on a regional scale. This is beyond current capability which, when considering ozone effects, can only provide approximate predictions of globally averaged surface temperatures (with some indication of latitudinal dependence). It is important to emphasize, however, that the simple models used to make such average temperature predictions do serve a valuable purpose--namely, to identify potentially important climate change mechanisms and to study climatic feedback and other physical processes. Hence, there is a need to continue to refine these simple models while work continues on improving the predictive capabilities of the more complete and detailed models of atmospheric circulation.

It is important to be able to determine whether significant change is taking place before an irreversible or otherwise deleterious trend is established. Unfortunately, because the natural variability in climate is so large, small but significant trends are easily masked.

2. Current Research

Short-term BACER funds to investigate possible ozone-induced climatic changes were allocated to three areas: (1) a workshop held at

the National Center for Atmospheric Research (NCAR) in June 1977; (2) NOAA studies of regional differences and the correlation of impacts with regional climate statistics; and (3) climatic presentations and discussions at the BACER workshop held at the University of Maryland in September 1977.

The NCAR Workshop participants repeatedly emphasized the importance of precipitation and regional changes. The workshop section on observations pointed out the extreme difficulty of detecting small trends, both because of natural variability and because of sampling problems. The section on general circulation models agreed that the importance of regionality and precipitation established an ultimate need for three-dimensional global circulation models that can predict ozone effects on planetary waves, blocking, and storm tracks. This capability does not exist now, and some evidence indicates that it may be extremely difficult ever to develop such a capability. In any case, at least a decade of sustained research will be required to develop a better understanding of the problem and of possibilities for attaining solutions.

The NCAR Workshop sections on simple climate models and the stratosphere reviewed current predictions of ozone depletion and resultant temperature changes. Current models predict an ozone column depletion of over 10% could occur within three to five decades if CFC releases continue at the 1975 rate (for details see NASA, 1977, and Hudson, 1977). The predicted depletion is largest above the ozone peak, as shown in Figure 3. (Ozone concentration typically peaks between 16 and 30 km.) One-dimensional radiative-convective models predict that a vertically uniform 10% decrease in ozone content will decrease global average surface temperature by 0.1 to 0.15°C. However, they also show that a lowering of the ozone peak, which is also predicted, would tend to increase surface temperatures. Hence, the two effects appear to be mutually offsetting relative to changes in surface temperature.

The predicted temperature effects are approximate because some potentially significant feedbacks have not yet been included in the models. Nevertheless,it does appear that the ozone-induced change in global average surface temperatures would be less than the decrease of

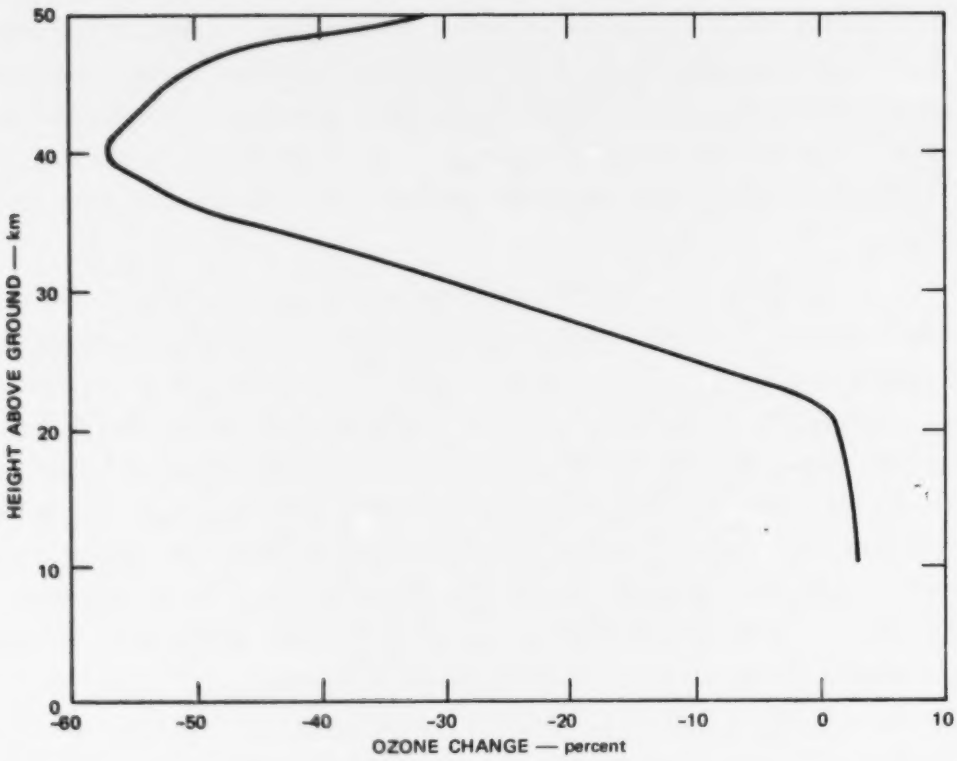


FIGURE 3 ONE-DIMENSIONAL MODEL CALCULATIONS FOR THE VERTICAL DISTRIBUTION OF OZONE CHANGE. Source: Geisler (1977).

about 0.3°C observed between 1944 and 1970 (see Section II-F, Figure 6). This reemphasizes the fact that the most important climatic effect induced by ozone depletion would probably be regional changes caused by modification of planetary wave behavior. The possibility of such changes must be taken seriously, since the ozone changes shown in Figure 3 would substantially alter the stratospheric temperature profile, which could in turn alter the stratospheric reflection and transmission coefficients for planetary waves. More importantly, latitudinal change in the temperature of the troposphere resulting from ozone depletion could alter the equator-to-pole heat flow--another important determinant of weather system motion. However, as stated above, there is currently no capability for reliably predicting these regional and precipitation effects that would result.

Because of the difficulties in numerically modeling regional climate effects, the NOAA-monitored studies have focused on paleoclimatological studies of what regional climates and impacts were like during previous periods of global atmosphere cooling or warming. These studies revealed marked spatial variations in regional temperature and precipitation during previous periods of overall hemispheric cooling or warming, and showed that very large precipitation changes often accompanied rather modest temperature changes (Webb, 1977, Wigley, 1977). Although these studies did not reveal preferred (i.e., repetitive) geographical patterns of climatic change that accompany general planetary warmings or coolings, they did establish powerful analytical techniques, which, when applied to larger data bases, might reveal such patterns. Uncovering such patterns could make it possible to anticipate the regional climatic changes associated with a future increase of atmospheric pollutants before advanced climate models are able to assess the situation theoretically (Sprigg, 1977).

3. Future Needs

Recommended climate research needs are summarized in Table 3. The first need, a climate workshop focused principally on stratospheric ozone-depletion effects, is warranted to minimize the potential redundancy

Table 3

CLIMATE RESEARCH NEEDS

Research Need	Benefits
• Climate Workshop. Organize and convene workshop on anthropogenic climate modification. Invite national and international experts in the field of climate modeling and monitoring. Assess the state of the art of potential global and regional climatic impact of anthropogenic atmospheric perturbations, such as ozone depletion, increasing burden of infrared absorbing species (CFC, CO_2, N_2O, H_2O), and aerosol particles.	Short term
• Statistical Analyses. Apply judicious statistical methods to existing climatological data, both to detect possible anthropogenic trends in climate variables and to design better monitoring systems.	Short term
• UV-B and Smog. Study effects on urban air pollution caused by an increase in UV-B induced by stratospheric ozone depletion.	Short term
• Climate Models. Assess by means of theoretical modeling, using an empirical data base, the climatic changes that may occur as a consequence of anthropogenic activity. The primary concern will be the alteration to the radiation budget by ozone removal, aerosol formation, and introduction into the atmosphere of other infrared absorbing/emitting species. Include latitude dependence and feedback by ice albedo and clouds.	Long term
• Trace Substance Monitoring. Monitor atmospheric trace substances (including aerosols) that play a central role in determining anthropogenic influence on climate.*	Long term
• General Circulation Models. Improve general circulation models to simulate the effects of ozone-depletion-induced changes in tropospheric temperature, stratospheric temperature, and winds on planetary waves and storm tracks. Improve cloud parameterization to permit inclusion of cloud feedback effects.†	Long term

*Research supported primarily by other agencies as specified by Section 154 of PL 95-95. EPA may support essential efforts for which other funding sources are discontinued.

†Research supported by other agencies as specified by Section 154 of PL 95-95.

in effort of the groups active in climate research. Also, climate modelers should benefit from added insight through information exchange. Changes in the surface incidence of UV-B radiation resulting from depletion of the stratospheric ozone layer also warrant special attention in the context of atmospheric conditions in connection with smog formation. In urban atmospheres UV-B is a critical factor in the photo-chemical transformation processes causing smog. The remaining needs in Table 3 represent continuations of existing research efforts.

E. Monitoring and Instrumentation

The instantaneous incidence of UV radiation at the surface is of very low intensity and varies markedly with wavelength. It is thus difficult to measure or to discern its variations. Useful evaluation of the amounts and effects of UV radiation requires (1) the development (or adaptation) of standardized instruments and methods for measuring and producing UV, (2) close collaboration between instrument builders and users, and (3) frequent cross-calibrations of both laboratory and monitoring equipment. The specific needs for UV detectors and sources, both in long-term monitoring and experimental studies, are summarized in Table 4 and described below.

1. Detectors

For both monitoring and experimental purposes there is a need for spectrally resolved measurements of UV radiation in the 290 to 320 nm range* with radiometric accuracy of about 10% and wavelength resolution of 10 nm or better. For monitoring purposes there is a need for long-term (at least several-year) measurements at enough locations to yield reliable means and trends for specific regions (including the oceans) and latitude bands. Prior to BACER there was virtually no such information available in the U.S., although a CIAP-initiated program had begun to provide regional monitoring of total (spectrally integrated) UV-B radiation, weighted according to the human sunburn spectrum (i.e.,erythemally weighted). Whereas these total, weighted measurements have yielded vastly more information than that available prior to CIAP, they do not provide the spectral information required to determine the effect of UV-B on processes with action spectra other than those that contribute to sunburn. (The action spectra for skin cancer and for plant damage are currently

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*The UV-B region spans 280 to 320 nm, but at the earth's surface the amount of radiation at wavelengths shorter than 290 nm is negligible compared to the amounts between 290 and 320 nm, so that coverage of this latter band is adequate.

Table 4

UV MONITORING NEEDS

Research Need	Benefits
• Radiometer Network. Continue the R-B network one year to yield 5-year data record. Correlate data with biological, epidemiological, and agricultural effects. Augment with spectro-radiometers.	Short term
• Standardization. Standardize all UV-B effects studies by requiring a regimen of frequent cross-calibration, using specific sources and procedures. Publish all measured irradiances and dosages in standard energy density units (e.g., $W/m^2/nm$; $J/m^2/nm$).	Short term
• Spectroradiometer Network. Continue development of low-cost, portable, automated, spectrally resolved UV-B detectors. Deploy at appropriate locations. Intercalibrate the NOAA Modified Dobson Spectrophotometer, the Robertson-Berger meter, and the Norris Spectrometer.	Short term
• Immersible Spectroradiometer. Continue tests and characterization of the immersible spectroradiometer.	Long term
• Personal Dosimeters. Develop and test personal dosimeters.	Long term

unknown.) It is this difference in action spectra for different biological effects that creates the need for spectrally resolved measurements. It is essential that spectrally resolved measurements, without weighting, be made and recorded, so that biological effects with action spectra different from that for erythema can be derived from the data base.

To permit the essential comparisons among different measurements, radiometers must satisfy the following criteria. They must provide output in internationally accepted physical units (e.g., $W/m^2/nm$), be easy to calibrate, have little long-term or temperature-dependent drift in either wavelength or radiometric calibration, and have cosine response accurate to 10% or better. (Cosine response refers to the instrument's ability to compensate for variations in the incident angle of radiation.) Instruments used for monitoring purposes should be especially durable, and simple for a non-specialist to clean, maintain, calibrate, and operate. For laboratory and growth-chamber studies, durability and simplicity are not as important as finer spectral resolution (than the 10 nm mentioned above) and compactness of the sensor unit.

Because of the great importance of UV-B effects on marine ecosystems (see Section II-C), submersible spectroradiometers with characteristics similar to those described above must be developed to permit measurements of UV-B attenuation in the aquatic environment. There is also a need for personal UV-B dosimeters that could be unobtrusively worn in studies to ascertain the effects of lifestyle on personal UV-B exposure.

There is also a need to improve current ozone-monitoring capabilities, both to permit early detection of significant trends and to refine relationships between ozone reductions and measured UV-B increases. It is important to note that improvement in current ozone monitoring capabilities could be achieved both through improved analysis techniques for existing instruments and data bases (for example, the satellite UV-B data), and through improved instrumentation and calibration procedures.

2. Sources

Stable, reproducible, and convenient sources are required for use both as solar simulators in biological studies and as references for instrumentation calibration. In the latter application it is especially important to provide a precise wavelength reference (e.g., a narrow spectral line), since wavelength uncertainty is the major source of radiometric error in field spectroradiometric UV-B measurements. (This uncertainty results from the very strong dependence of intensity on wavelength near 300 nm; for example, a wavelength error of 0.1 nm leads to a radiometric error of 10% to 15% in this spectral interval. For this reason NBS recommends performing a wavelength calibration before each spectral measurement. See, for example, NBS, 1977.)

3. Current Research

a. Review of Measurement Uncertainties

BACER funds supported a review by NBS of the accuracies currently achievable in laboratory and field UV-B measurements (NBS, 1977; Kessler, 1977). The various sources of error were identified and evaluated in terms of their contribution to overall measurement uncertainty. It was concluded that, because of the strong dependence of UV-B spectral irradiance on wavelength, wavelength uncertainties are the largest source of radiometric error in typical field measurements. Hence, a check of wavelength calibration before each measurement is recommended. Typical state-of-the-art measurement errors were shown to range from 3% to 10% in the laboratory and from 10% to 45% in the field. Progress in reducing errors has been rapid in the past year and reductions by a factor of three to five seem probable within the next five years, provided that vigorous support is continued. Specific recommendations were made for instrument specifications that would reduce field measurement uncertainty to 10% or less.

b. Robertson-Berger Sunburn Meter Network

A portion of the short-term BACER budget was devoted to continuing measurements and analysis in the primary U.S. UV-B monitoring

effort, involving a network of Robertson-Berger (R-B) sunburn meters (Machta and Hass, 1977). These instruments, first built in the spring of 1973, measure a weighted integral of UV radiation, with the weighting designed to approximate the erythemal action spectrum (Urbach et al., 1974). They have a cosine response that is accurate to within 10%, and a sensitivity reproducibility of ±5%, and provide an automatic output each one-half hour. The output is not in energy-density units, but rather in "counts." However, the integral outputs of all R-B meters are matched to within ±5% at the time of construction, and their relative spectral response is tested by using a double monochromator in the laboratory. A conversion factor from "counts" to energy density has been derived by comparing data measured by R-B meters and collocated Modified Dobson Spectrophotometers (MDSs--units specially modified by NOAA with a mask to match the erythemal response). The R-B and MDS measurements were highly correlated*, suggesting that any differences in spectral response between the R-B and MDS instruments are of little importance in atmospheric monitoring.

By the end of 1977, four years of UV-B data will have been acquired with the R-B network. The primary results achieved during the period of BACER funding were: (1) a refined determination showing that the "amplification factor"--i.e., the ratio of relative UV enhancement to relative ozone depletion--is very close to the theoretically predicted value of 2 (though somewhat dependent on sun angle, turbidity, and ozone amount); and (2) derivation of a simple regression equation relating annual erythemally-weighted UV-B dosage in the U.S. to latitude and cloudiness of location.

c. Norris Spectroradiometer

With the aid of BACER funding, K. H. Norris of the Department of Agriculture (USDA), has developed a UV (250 to 370 nm) spectroradiometer that satisfies nearly all of the criteria stated in Section II-E-1 (Norris and Rowan, 1977). It uses a teflon bubble entrance window

*Correlation coefficient of 0.95.

to achieve cosine response accurate to within ±10%, a monochromator to achieve wavelength resolution of 2 nm, and a linked photomultiplier detector, logarithmic amplifier, digital voltmeter, and programmable calculator to achieve flexible, automatic operation with a radiometric precision of ±2% and accuracy of ±5%. The programmable calculator permits simple checking and resetting of the wavelength calibration with a mercury arc lamp; it also stores the system spectral response and automatically corrects for spectroradiometric calibration. A spectral scan, with wavelength steps of 1 nm, is achieved in 5 minutes. Thereafter the detailed spectral data are printed out, along with an integral weighted by a preprogrammed action spectrum. Stray light rejection of 10^{-4} is achieved with a single monochromator, and 5×10^{-8} is achieved with a double monochromator. Sensor heads for the single and double monochromator units measure 28 × 20 × 10 cm and 28 × 25 × 10 cm, respectively. Versions of the instrument are now manufactured by several companies.

d. Immersible Spectroradiometer

Scripps Institute of Oceanography (University of California) is developing an immersible spectroradiometer for studies of UV-B attenuation in aquatic environments (Smith, 1977). This has many features that are similar to the Norris Spectroradiometer described above. It uses a teflon-bubble entrance window, a double monochromator, a photomultiplier tube, a microprocessor, and a programmable calculator for flexible, automatic operation and ease of calibration. Initial underwater field tests were made in October 1977.

e. Argon Mini-Arc

Short-term BACER funds supported the continuing development at NBS of the Argon mini-arc, a transfer standard of spectral irradiance that is compact enough to be taken to the field for simple instrument calbration. Its spectral irradiance at 300 nm approximates that of the sun at the earth's surface and is stable to within ±2%. Units can be rented from NBS on a weekly basis by field and laboratory experimenters (NBS, 1977).

f. BZ Fluorescent Lamp

The BZ fluorescent lamp was developed at NBS with short-term BACER support. It provides output in the 275 to 350 nm spectral

range with precision and accuracy of 2 to 3% and 5 to 6% respectively. In the 280 to 300 nm range the spectral output closely duplicates the solar spectral irradiance at the earth's surface. Calibrated units can be purchased for $400 (NBS, 1977).

F. Integrated Assessment

1. Background

The development of rational policies to regulate CFCs and other threats to the atmosphere requires that available information be assembled in some logical manner in a system designed for use by decision makers. Initial efforts in this area were presented at the BACER workshop in September and continue at the University of Maryland. These efforts have provided the framework for an optimum control (decision) model capable of accommodating the complexities and uncertainties surrounding the question of ozone depletion. In addition to providing a basis for regulatory decisions, an optimum control model also indicates how the decision could be improved by reducing the uncertainty associated with the variables in the model. With this information, research budgets may be allocated to those topics that will be of most significance in making the policy or regulatory decision. A major part of this model is the specification of the linkages between the physical and biological impacts and the social and economic consequences. There are many areas of uncertainty regarding the response of the social and economic systems due to changes in UV-B and climate, in addition to the basic uncertainty as to whether ozone depletion would in fact lead to climatic change.

2. Current Research

a. Social and Economic Effects

Impacts from ozone depletion lead to a host of economic and social concerns. Increased UV-B radiation directly affects humans and other biological systems and subsequently leads to secondary social or economic impacts (e.g., health care costs, and reduced crop yields). Aside from increased UV-B incidence, ozone depletion could result in

other changes in the incidence of solar radiation, including IR and visible light, giving rise to potential changes in the climate. These climatic changes also lead to secondary social or economic impacts. Research to date has focused on reducing uncertainties of the primary effects. Studies on social and economic issues have proceeded at a slower pace, awaiting quantification of these primary effects on climate, health, and other biological systems. To provide some insight on the complexity of the issues and the general magnitude of the costs involved, the relationships between climate change and associated economic impacts are considered below.

The U.S. economy is highly sensitive to variations in weather and climate. This sensitivity arises through weather effects in three principal areas: (1) food production, (2) energy demand, and (3) other aspects of human life that are subject to disruption by weather. An initial comprehensive body of research on the economic and social impacts of climatic change was undertaken under the auspices of CIAP. Since the physical and biological phenomena governing ozone depletion and UV-B impacts were poorly understood, the economic analyses conducted under CIAP were parametric in approach. Consequently, there exists considerable uncertainty in the magnitude of the impacts estimated.

One of the CIAP studies addressed the economic effects of a 1°C decrease in mean annual temperatures. While the estimates were highly speculative, they served to identify the economic impacts and estimate the general magnitudes of the costs involved. Annual impacts were expressed in terms of 1974 dollars and ranged as high as $3 billion due to decreased forestry production alone. Other areas (e.g., rice production, marine resources, and health care exclusive of skin cancer) had comparable adverse effects.

There are several other examples of climatic variability affecting food supplies, energy demand, and other aspects of human life. The next example demonstrates the need for a technique to quantify the effect of ozone depletion on regional temperature and precipitation. Consider first the record of world grain reserves shown in Figure 4.

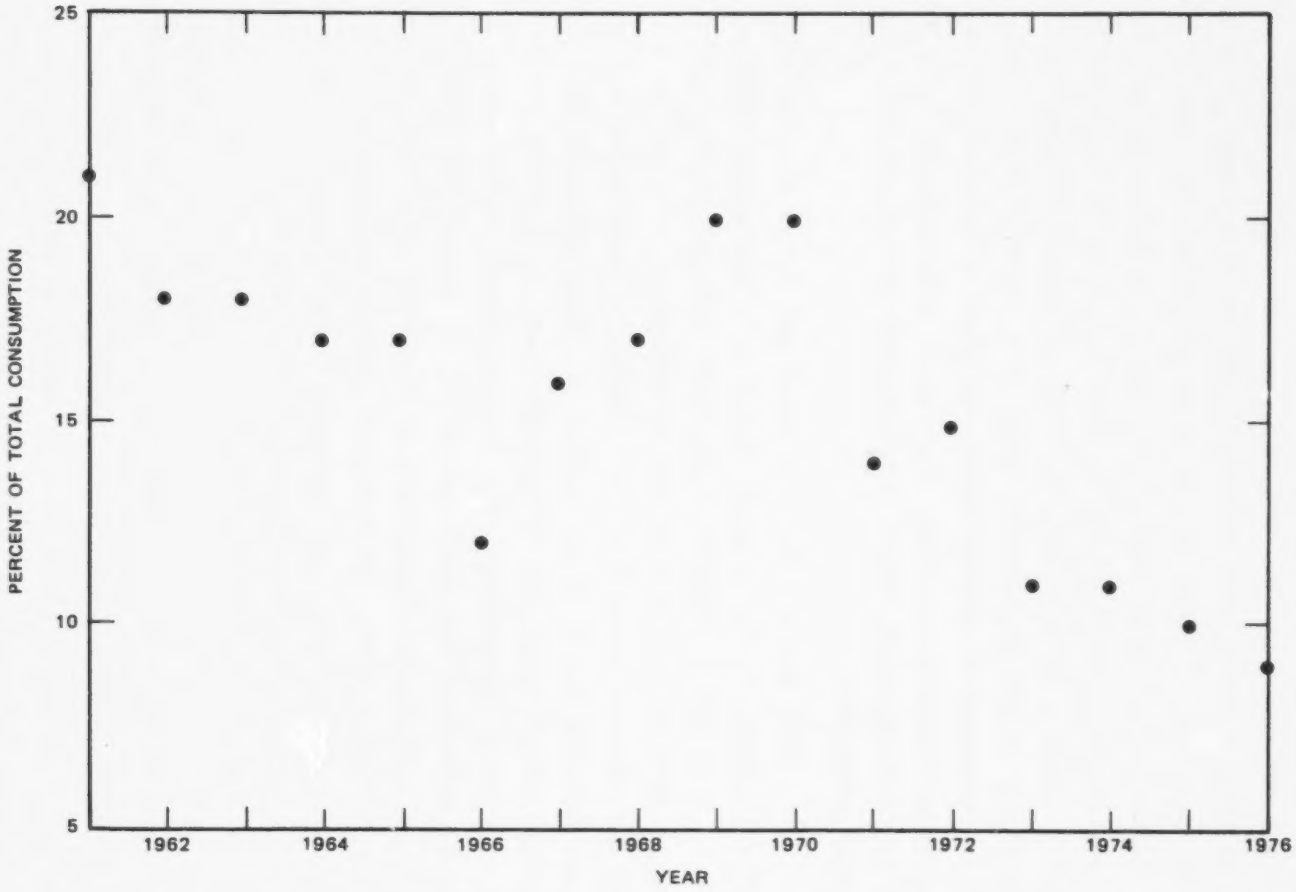

FIGURE 4 WORLD RESERVES OF GRAIN AS PERCENT OF TOTAL ANNUAL CONSUMPTION (1961-1976)

World grain reserves have been declining during the past 10 or 15 years and are now approximately at the level of weather-induced fluctuations in annual yield (Strommen, 1977). Figure 5 shows a record of weather-related impacts on grain production in the two largest grain-producing regions of the globe, and Figure 6 shows the record of global average surface temperature. It can be seen that there was a rather steady decline in global average surface temperature during at least the first 15 years of the grain-yield record. Nevertheless, although there were many weather-related yield decreases during this period, there is no evident relationship between the frequency of weather impacts on grain production and the global average temperature. Also, there is no simple relationship between the set of years when U.S. yields were affected and the set when USSR yields were affected.

This lack of simple relationships occurs for two reasons. First of all, precipitation changes, rather than temperature changes, were the major reason for weather-related crop impacts in many years (and there is no known simple relationship between global average surface temperature and regional precipitation). Second, climatic patterns that reduce agricultural yields in one region can often result in more favorable climate change in another region, and hence in improved yields there. Another example of the importance of regionality and precipitation is provided by the severe winter of 1976-1977. In that winter the eastern United States experienced record cold and heavy snowfall while California suffered a record drought. The severe weather in the east not only increased energy demand but also disrupted transportation and threw many people out of work while fuel supplies were interrupted. The total cost to the U.S. economy was far in excess of the cost of additional fuel consumption, and in fact required revision of President Carter's targets for U.S. economic performance. Additional costs were later incurred by the agricultural effect of the California drought.

At this stage it is not possible to accumulate impacts and arrive at a total cost for a hypothetical change in temperature or precipitation, because all the impacts have not been identified and quantified. However, from the figures presented, it is obvious that

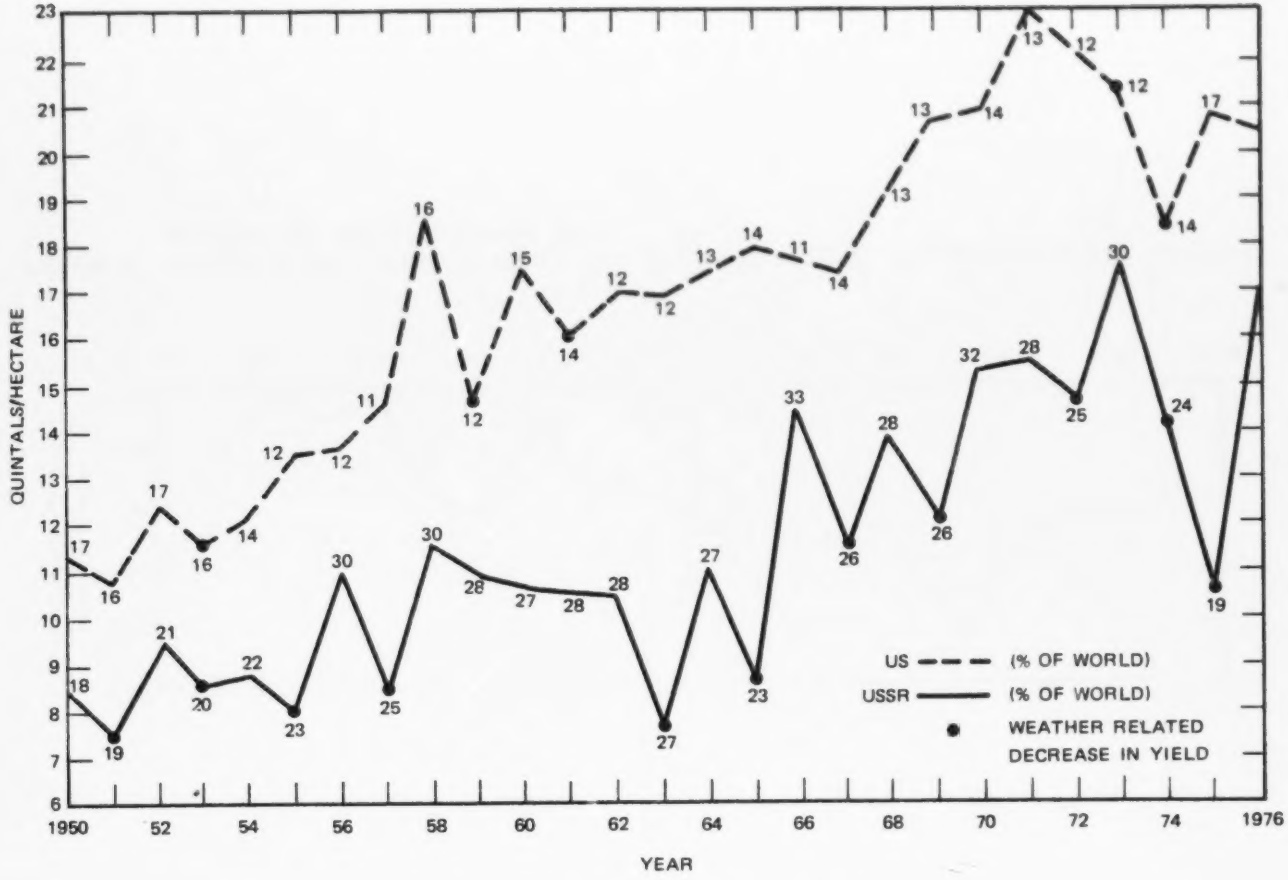

FIGURE 5 WORLD WHEAT YIELD, 1950-1975

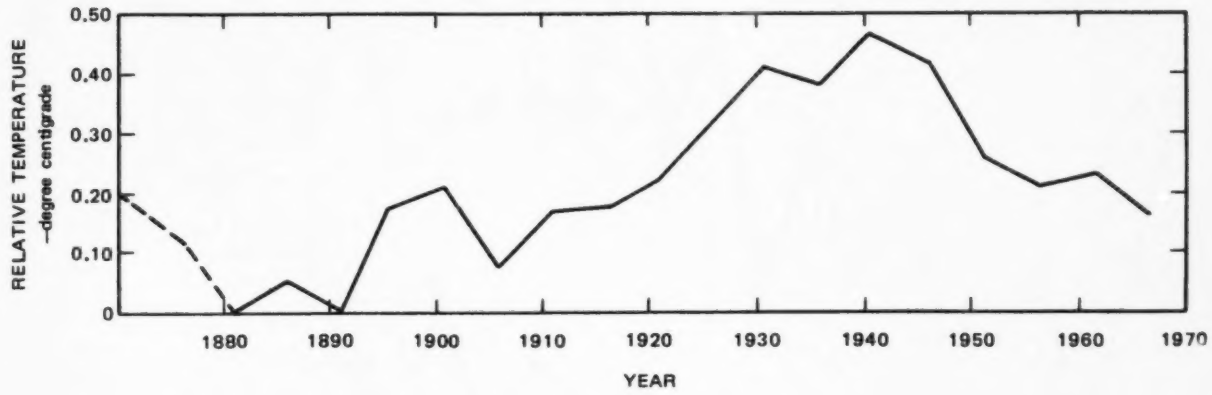

FIGURE 6 VARIATION OF GLOBAL MEAN SURFACE AIR TEMPERATURE. Five-year averages from 1880-1884 to 1965-1969. Source: Strommen (1977).

there is a chance for substantial losses in several areas of human activity.

b. Research to Support Regulatory Decisions

By the time PL 95-95 was enacted, research programs had become more focused toward providing a framework for regulatory decisions. At about this time the economics department of the University of Wyoming completed a cost-benefit analysis of nonessential uses of CFC for the EPA; A. D. Little and International Research and Technology each completed studies on the economic impact of regulating CFC emissions; and RAND currently is undertaking a more rigorous analysis of data needs and economic impacts on industry of possible regulation of non-aerosol CFC emissions.

On the topic of regulatory alternatives, the University of Wyoming examined the costs and benefits of regulations directed toward the various uses of fluorocarbons. This preliminary cost-benefit study brings out the difficulties that one encounters when working with large uncertainties regarding the physical effects of fluorocarbons. The University of Wyoming group suggests research strategies to reduce the uncertainties in the physical realm while attempting to minimize the costs of adverse and irreversible effects of fluorocarbons. With regard to the evaluation of regulatory alternatives, it appears that combining the expected benefit criteria with safety-first concepts would have a high payoff.

Toward the goal of providing decision makers with the means of making an integrated assessment, the BACER program is currently funding development of an optimum control model for integrating the physical, biological, and economic findings. The purpose is to provide the decision maker with a system for evaluating alternative control (and non-control) strategies.

3. Future Needs

Past work has identified many gaps and uncertainties regarding the understanding of ozone depletion and the consequences for existing

economic and social systems. Nevertheless, it is necessary to integrate the available information and to establish a framework for future regulatory decisions. Accordingly, Table 5 identifies three programs with short-term payoffs that will lead to the efficient realization of these goals.

The first need, an interdisciplinary workshop, helps establish a common foundation of knowledge and needs for the scientific community and decision makers alike. The second need, an optimum control model, is the decision maker's primary tool in assessing the effect of various regulatory strategies. This need also encompasses improvements in the individual components of the model such as:

- Development of an integrated optimum control model to assess the effect of regulatory strategies.
- Estimation of the value of additional information on direct-indirect effects.
- Improvement of methods or models for quantifying the economic and social effects of climatic change.
- Assessment of the alternative measures of morbidity and mortality for use in evaluating costs.
- Assessment of the economic and ethical issues associated with risks imposed on current population and on future generations.

Participation at the 1977 BACER workshop (EPA, 1977) raised ancillary issues, such as the need to include the costs of regulating in any policy analysis. Other suggestions were directed to topics that would (1) ensure a holistic approach encompassing all identifiable benefits and costs, (2) help to establish a baseline from which costs and benefits could be measured, and (3) consider distributional aspects--both international and within the United States. Little was said regarding social impacts--in large part because behavioral responses are difficult to predict.

Table 5

INTEGRATED ASSESSMENT NEEDS

Description	Benefit
• Interdisciplinary Workshop. Continue to support an interdisciplinary workshop along the lines of the September 1977 BACER workshop; this will enable the latest research findings to be incorporated into the decision process (model).	Short term
• Optimum Control Model. Continue development of the optimum control (decision) model, which assesses the effect of regulatory strategies. Refine the social and economic components by supporting further cost-benefit analyses.	Short term
• Prioritorize Future Research. Identify the most serious data gaps in the integrated assessment process. Rank these by estimating the value of the additional information against the cost of obtaining it.	Short term

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